17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China

The Ultrasonic Phased Array Inspection Technology Used in Tubular Joint Welds of Offshore Platform Structures

Baohua SHAN [1], Hua WANG [2], Xinyu Zhao [3], Zhongdong DUAN [1], Jinping OU [1,4]
[1] School of Civil Engineering, Harbin Institute of Technology, Harbin, China
Phone:+ 86 45186283065, E-mail:shanbaohua@hit.edu.cn, duanzd@hit.edu.cn
[2] School of Transportation Science and Engineering, HIT, Email:hitwh@hit.edu.cn
[3] School of Material Science and Engineering, HIT, Email:xyz88@hit.edu.cn
[4] Dalian University of Technology, Dalian, China, Email:oujinping@hit.edu.cn

Abstract

Aimed at the practical requirement of tubular joint welds inspection of offshore platform structures, the ultrasonic phased array inspection algorithm for offshore platform structures is proposed in this paper, and the ultrasonic phased array inspection system for offshore platform structures is developed. The experiment of tubular joint model is performed with the ultrasonic phased array inspection system for offshore platform structures, the flaws characteristic could be exactly estimated and the flaws size could be measured through ultrasonic phased array inspection software system. Experiment results show that the ultrasonic phased array inspection algorithm for offshore platform structures is feasible, the ultrasonic phased array inspection system could detect flaws in tubular joint model, the whole development trend of flaws is factually imaging by the ultrasonic phased array inspection technology of offshore platform structures.

Key words：Ultrasonic phased array; Inspection; Offshore platform structures; Tubular joint welds

1. Introduction

Offshore platform structures operate in a harsh environment and are subjected to a variety of cyclic loads such as wind and waves, and flaws are usually easy to come into being in welded tubular joints. In order to guarantee the reliability of the offshore platform structures operations, different NDT methods are used to detect offshore platform structures, the undetected area of conventional manual ultrasonic inspection method with single transducer increases the incipient fault of security of offshore platform structures[1], it is necessary to research a synthetic and intelligent evaluation method used to detect tubular joint welds flaws of offshore platform structures, and the development of ultrasonic phased array inspection technology resolves this problem.

In fact, the ultrasonic phased array inspection imaging technology has been intensively developed in the field of medical imaging[2]. In NDT, the ultrasonic phased array inspection imaging technology has been paid attention very recently, since 1990s, in foreign countries the ultrasonic phased array inspection imaging technology was gradually used in NDT industry such as inspection of weld[3], turbine blade[4] and taxi axle[5], etc.

At present, the domestic research of industrial NDT field is still in stage of exploring, which was mainly centralized on the optimal design of ultrasonic phased array and the development of ultrasonic phased array circuit system, the industrial application was investigated little. Aimed at the problem, this paper will present application example in offshore platform structures inspection.

2. Inspection algorithm

2.1 Definition of inspection zone

The tubular joint weld inspection of offshore platform structures usually carried out on the branch pipe, so the coordinate system of inspection algorithm is defined as shown in Figure1. The ektexine of branch pipe is defined as the positive direction of X axis , the crossing point between the slope line of branch pipe and the ektexine is selected as the origin of coordinate, and the direction pointing to the inwall of branch pipe is chosen as the positive direction of Y axis.

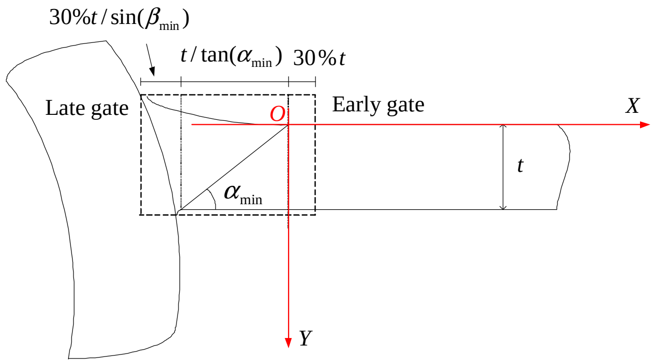


Figure 1. Sketch map of coordinate system of inspection algorithm

In order to guarantee the detection of flaws, the inspection zone of tubular joints weld should include such zones where flaws are easy to coming into being as the side fusion area of main pipe, the side fusion area of branch pipe and root of weld, etc. References to the definition of inspection zone width of GB11345-89, the early gate and late gate of tubular joints weld of offshore platform structures are defined as shown in Figure1. The early gate width of ultrasonic phased array inspection zone of tubular joints weld is defined as 30 percent of the wall thickness of branch pipe considering the condition of flat plate. For the groove angle of tubular joints weld of offshore platform structures varies in certain range, which isn't a fixed angle, then the maximal weld width corresponding to the minimal groove angle is selected as the width of tubular joints weld considering the limiting case, including the weld gap value. The width of late gate is defined by $30\%t/\sin\beta_{min}$ considering the condition of curved face, over here β_{min} is the minimal inspection angle, t is the wall thickness of branch pipe, the minimal ultrasonic inspection angle of tubular joints weld of offshore platform structures is 45°, so β_{min} is equal to 45°. The inspection zone width defined includes all kinds of weld zone profile corresponding to different groove angle, then the gate width is a fixed value aimed at all groove angle of certain tubular joint.

2.2 Selection of inspection angle

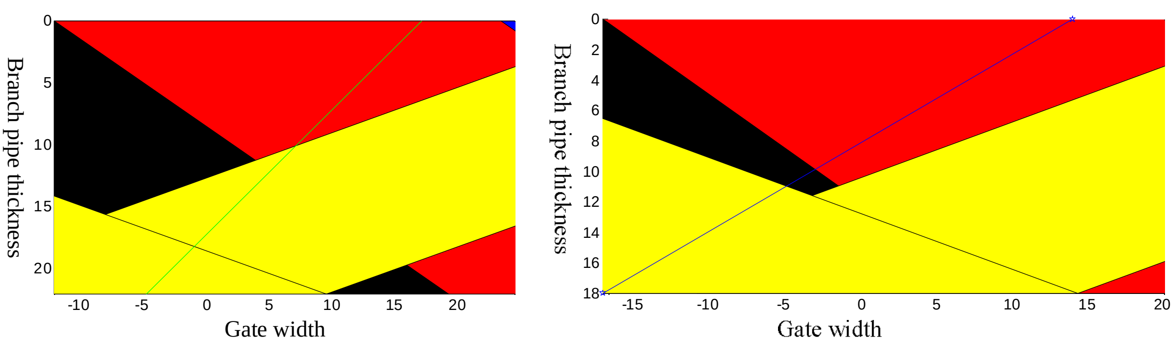
Manual ultrasonic detection method of offshore platform structures usually use transducer whose inspection angle might be 45°, 50°, 52°, 55°, 58°, 60°, 65°, or 70°, references to the inspection angle requirement of manual ultrasonic detection method, initially phased array ultrasonic technology also adopt these inspection angles, three inspection angles of 50°, 55° and 70° are finally adopted through algorithm selection.

Firstly, the arrange positions of initial sound beam and terminal sound beam of each inspection angle are calculated in inspection arithmetic, toward secondary sound wave inspection, namely the inspection angle of 45°, 50°, 52°, 55°, 58°, 60°, or 65°, the initial sound beam of each inspection angle requires to intersect the ektexine of branch pipe at the late gate, the terminal sound beam of each angle requires to cross the ektexine of branch pipe at the early gate. Toward the primary sound wave inspection, namely the inspection angle of 70°, the initial sound beam requests to intersect the ektexine of branch pipe at the coordinate origin, the terminal sound beam requests to cross the ektexine of branch pipe at the maximal groove angle. And then the wedge sloping surface positions where central element of initial sound beam and terminal sound beam locate are respectively calculated, toward secondary sound wave inspection, if central element of initial sound beam is less than 1, or central element of terminal sound beam is greater than 64, then this inspection angle should be quitted, otherwise this inspection angle should be used, and the inspection angle selection method of 70° keeps to the same rule, at last three inspection angles of 50°, 55° and 70° are adopted according to the inspection angle selection rule.

2.3 Arrangement of sound beam combination

In order to guarantee sound beam combination could completely cover the inspection zone of different inspection object, the definitive inspection angle of 50°, 55° and 70° reorder their logical element combination. The sound beam combination arrangement process is very similar to the process of inspection angle selection in working principle, but not identical.

The collocation of inspection angles of T shape tubular joint with 22mm wall thickness and Y shape tubular joint model with 18mm wall thickness are obtained through incorporating three inspection sound beam combination, the oblique line in Figure 2 denotes the minimal groove angle of tubular joint, a color in Figure 2 expresses zone covered by a inspection angle, the combination of inspection angle entirely cover the inspection zone of tubular joint, the phenomena of undetected zone doesn't exist from Figure 2.



a) T shape tubular joint model　　b) Y shape tubular joint model of 60 degree

Figure 2. Inspection angles combination

3．Ultrasonic Phased Array Inspection Imaging System

As showed in Figure 3, the ultrasonic phased array inspection imaging system for offshore platform structures is integrated on the basis of the each module and the exploitation of subsystem, which is made up of computer, ultrasonic circuit system, scanning device, phased array transducer and inspection imaging software system. It has the functions of controlling ultrasonic transmission and reception, controlling sound beam steering and focusing, controlling scanner moving, receiving flaw information and position formation, restructuring flaw image and commenting damage.

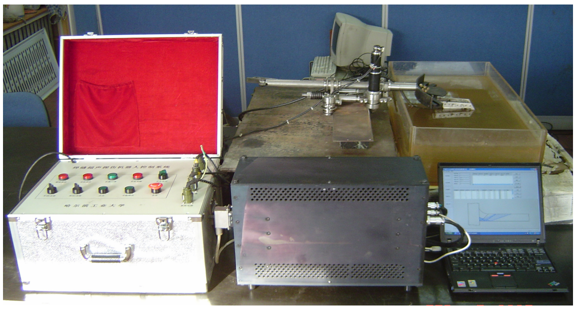


Figure 3. Photo of ultrasonic phased array inspection imaging system

The ultrasonic linear phased array was manufactured according to the inspection algorithm, the transducer has 64 elements and the center frequency is 5 MHz, the inter-element spacing is 1mm, and the element width is 0.9mm, the lateral elevation is 12mm. The ultrasonic phased array transducer is waterproof, which could resist the pressure of 6MPa and be applied to the underwater NDT.

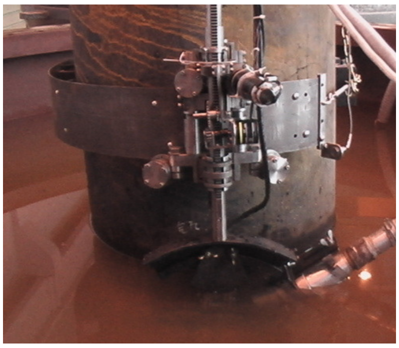
The ultrasonic phased array circuit system may be divided into three main units: master unit, main board unit and transmit/receive unit. The circuit system could support 64 elements phased array transducer and handle 32 active elements at most. It has the characteristics of celerity, real time, integration, which could accomplish all kinds of ultrasonic phased array inspection arithmetic of offshore platform structures.

Scanning device is composed of the scanner mechanism, clear water vision system and the electric control system, The scanner is a robot with four freedoms, the first is circumferential motion around branch pipe, the second is axial motion along axis of branch pipe, and the residual two are swing motion. Scanner mechanism comprises creeping vehicle, bodywork, track, expansion bracket, swing track, swing axis and probe holder. When working, the track is cling to the ektexine e of branch pipe with magnetic force, the creeping vehicle moves along track for accomplishing circumferential motion around branch pipe, at the same time the probe holder moves along swing track. Transducer is held with probe holder, the former two freedoms works harmoniously according to the definite rule, which tracks tubular joints weld with transducer and meets inspection algorithm requirement.

The imaging software system is compiled according to the inspection algorithm of offshore platform structures, which includes six function modules, namely debugging module, project management, control module, image display, flaw analysis and hardware drive. The inspection imaging software system could transfer inspection item for descrying data, generate the new inspection plan or inspection item for detection, show four display modes of flaw image, complete flaw analysis and automatically create the inspection report.

4. Tubular Joint Model Experiment

In order to simulate practical flaws of offshore platform structures and validate phased array ultrasonic inspection imaging technology for offshore platform structures, the T shape tubular joint model and the Y shape tubular joint model with 60 degree of offshore platform structure with a scale of 1:1 were manufactured, and they have the same steel type with practical offshore platform structures, which were made of D32 steel. The branch pipe of T shape tubular joint model is 600mm in diameter, 22mm in wall thickness and 1000mm in length, the main pipe of T shape tubular joint model is 1200mm in diameter, 26mm in wall thickness and 1500mm in length. The branch pipe of Y shape tubular joint model of 60 degree is 500mm in diameter, 18mm in wall thickness and 1000mm in length, the main pipe of Y shape tubular joint model of 60 degree is 900mm in diameter, 26mm in wall thickness and 1200mm in length. The experiment photo of tubular joint model is shown in Figure. 4. Some artificial defects such as crack, slag inclusion and gas porosity, etc. were also manufactured on the tubular joint model. The identical processing method adopted in practical engineering was used to the weld surface, sanding was made on the tubular joint model for erasing the influence of residual stress.



a) T shape tubular joint model

b) Y shape tubular joint model of 60 degree

Figure 4. Experiment photo of tubular joint model

The professional detection personnel of Shengli oil field adopted the manual ultrasonic inspection method to detect the tubular joint model, the mobile oil was selected as the couplant, ordinary single transducers of 45 degree with focusing and 70 degree whose center frequency are 5MHz were used to detect the tubular joint model, the gain of 4dB was compensated considering curvature deterioration, the criteria of API-RP-2X was followed during detection, and manual ultrasonic inspection report was offered and the detection result was shown in Table.1 and Talbe.2.

As shown in Figure 4, during experiment tubular joint model was immerged in turbid water, the track of scanner was installed on the appropriate position of branch pipe ektexine, the track direction was adjusted to parallel the circumferential direction of the branch pipe, the track of scanner was adsorbed on the ektexine of branch pipe with two-bank magnet base of fixed distance. And then creeping vehicle was assembled from one end of the scanner track and adjusted to keep normal movement attitude, the caging device was set on the two end of track for preventing the creeping vehicle from running out the track, the curb chain was used to lock the scanner track in order to keep the track from sloughing by reason of the scanner weight. Subsequently the scanner mechanism was installed on the track, the expansion bracket was assembled on the creeping vehicle, the swing device was fixed on the front-end of the expansion bracket, the probe holder and the clear water vision system were fitted on the swing device. The phased array transducer was entirely immerged in water, the direction, elevation, level position and longitudinal distance of the phased array transducer were adjusted with the wedge for satisfying the algorithm request, according to the inspection position, swing angle of transducer was adjusted in order to keep transducer perpendicular to shape tubular joints weld. Finally the scanner began detection according to the inspection algorithm request. The inspection result of T shape tubular joint model was shown in Table1, and the inspection result of Y shape tubular joint model was shown in Table 2.

Table 1. Inspection result of T shape tubular joint model

Flaw number	Flaw length (mm)		Flaw height (mm)		Flaw comment
	Phased array transducer	Conventional transducer	Phased array transducer	Conventional transducer	
90-1	36	38	15	14	Gas porosity
90-2	14	15	4	5	Slag inclusion
90-3	6	5	4	4	Gas porosity
90-4	40	40	8	10	Crack

Table 2. Inspection result of Y shape tubular joint model of 60 degree

Flaw number	Flaw length (mm)		Flaw height (mm)		Flaw comment
	Phased array transducer	Conventional transducer	Phased array transducer	Conventional transducer	
60-1	30	30	8	6	Lack of fusion
60-2	22	23	7	10	Slag inclusion
60-3	16	15	7	6	Crack
60-4	7	5	6	6	Gas porosity

5. Conclusion

In this paper the ultrasonic phased array inspection algorithm for offshore platform structures is proposed according to inspection requirement, and the ultrasonic phased array inspection imaging system is integrated. The experiment was performed on the two tubular joint models with artificial defects, the experiment results show the validity and practicability of the ultrasonic phased array inspection technology, the experiment results indicate that the flaws detected by the manual ultrasonic inspection technology could be found again by the ultrasonic phased array inspection technology, the flaws size measured by the latter is close to the former, and the whole trend of development of flaws are factually imaging by the latter.

6．Acknowledgements

The paper is supported by “863” of high-tech research and development program of China (No. 2006AA09Z353) and national nature science foundation of China (No. 50609002)

References

[1] Cheng Zhihu, “Ultrasonic Detection of T, K, YTubular Joints Weld”, Nondestructive Testing, Volume 16 Number 8, August 1994, P234-240.

[2] Olaf T. Von Ramm, Stephen W.Smith, “Beam steering with linear array, Biomedical Engineering”, IEEE Transactions on, Volume30 Number 8, August 1983, P438-452.

[3] Blanquet P. etc, “Application of Array Transducers to Health Monitoring of Aeronautic Structures”, 14th WCNDT, 1996, Volume 4, P2057-2060,

[4] A Lamarre, N Dube, P Ciorau, “Feasibility study of ultrasonic inspection of turbine blade root using phased array probes”, Insight, Volume 42 Number 9, September 2000, P586-589.

[5] D. Utrata, R. Clark, “Groundwork for rail flaw detection using ultrasonic phased array inspection”, Review of Progress in Quantitative Nondestructive Evaluation, Volume 22, 2003, P799-805.